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Military Requirements for JP-8 Reformers and Solid Oxide Fuel Cell Power Systems

Jeffrey D. Stangl, Robert O. Wertz, and Franklin H. Holcomb

December 2005

2 kW System

3 kW System

30 kW System

60 kW System

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Final Report

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ABSTRACT: This work represents an early step in the military Solid Oxide Fuel Cell (SOFC) development process. This study identifies: (1) the military's current and future electric power needs and capabilities, (2) the requirements for building a military SOFC power system with design recommendations, and (3) an initial approach to a Modularization Plan for developing military SOFC technology. The goals of this Modularization Plan will be to minimize procurement, training, and maintenance costs.

Existing generators will be replaced with future electric power systems requiring reduced weight and footprint. Fuel efficiency goals will reduce fuel tanker fleet size and further decrease the logistical footprint. Military Standards, Specifications, and Handbooks pertaining specifically to SOFCs are not available, nor planned. This report identifies documents pertinent to the development of solid oxide fuel cell systems (<60 kW) based on information gathered through assessments of current applications and procurement requirements for military electric power. The report offers design recommendations to minimize the procurement cost of the SOFC system. The report discusses current capabilities, provides high-level considerations for a modularization plan, and identifies potential benefits of adopting a modular approach to SOFC systems, which is anticipated to reduce training, streamline the maintenance requirements, and reduce logistics.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	(5/9) x (°F – 32)	degrees Celsius
degrees Fahrenheit	(5/9) x (°F – 32) + 273.15.	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

***Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted under project "Solid Oxide Fuel Cells (SOFCs)"; Work Unit No. BF707G. The technical monitor was Mr. Bob Boyd, Office of the Director, Defense, Research, and Engineering (ODDR&E).

The work was performed by the Energy Branch (CF-E), of the Facilities Division (CF), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was Franklin H. Holcomb. Part of this work was done by Jeffery Stangl and Robert Wertz, Concurrent Technologies Corporation (CTC), Johnstown, PA under Contract Number: DACA42-02-2-001. The technical editor was William J. Wolfe, Information Technology Laboratory. Dr. Thomas Hartranft is Chief, CEERD-CF-E, and L. Michael Golish is Chief, CEERD-CF. The associated Technical Director was Gary W. Schanche, CEERD-CVT. The Acting Director of CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

> Electric power, provided primarily by mobile generator sets in the combat zone, is the lifeblood of the Armed Forces.*

The Department of Defense (DOD) makes significant use of Mobile Electric Power (MEP) generators operated from logistic fuels in the range of 2 kW to 60 kW. These systems account for 100,691 individual units with a combined generating capacity of 1,037,725 kW. However, additional units of the current design will not be available from manufacturers after 2008 because they do not comply with future U.S. Environmental Protection Agency (USEPA) requirements. While the military can continue to use existing units, these units will eventually become unsupportable as manufacturers discontinue production and support for the units. Moreover, the DOD has developed goals for a new generation of USEPA-compliant logistic fuels powered MEP generators that will perform better than the current generation of MEP systems. These goals include reduced weight and acoustic signature; and improved fuel consumption, reliability, and repair time. While these goals may be met by combustion based units, Solid Oxide Fuel Cell (SOFC) based MEP systems are also a potential alternative.

The U.S. Department of Energy (DOE) Solid State Energy Conversion Alliance (SECA) program is a collaborative effort between the Federal Government, independent research organizations, U.S. industry, and academia, the ultimate goal of which is to develop low-cost, remote/stationary, SOFC power systems in the 3 kW to 10 kW range. Currently, the SECA program has a long time frame for SOFC development and does not address the DOD's technology development needs regarding fuel and environmental operating requirements. While SECA's low-cost solution may be ideal for some applications, the military has a great and immediate need for remote sources of cost and energy efficient power with reduced environmental emissions and decreased logistical burdens. Contributing to this need is the fact that

* DOD Program Manager Mobile Electric Power (PM-MEP) web site, accessible through URL: http://peocscss.tacom.army.mil/pmMEP.html

some aging power systems in the field will become increasingly difficult to maintain as industry ceases to support systems that are judged inefficient by today's standards.

Consequently, there is a need for the "militarization" of SECA-based SOFC technology in the near-term with the following characteristics. The fuel cell power systems must be:

- modular in design
- able to operate within the range of readily available defense logistic fuels and provide stable, continuous power
- rugged enough to be carried into the field, set up, and operated unattended
- capable of generating 3 kW to 10 kW of power
- energy efficient and able to meet the guidelines for environmental emissions and logistical burden reductions.

Researchers at the U.S. Army Engineer Research and Development Center, Construction Engineering Research Lab (ERDC-CERL) have actively participated in the development and application of advanced fuel cell technology since the early 1990s. In that time, the Department of Defense (DOD) has installed the largest fleet of fuel cells in the world. Because the DOD need for power systems with the above characteristics is more urgent than the current SECA time frame, ERDC-CERL has partnered with Concurrent Technologies Corporation (CTC), the Gas Technology Institute (GTI), and the Air Force Research Laboratory (AFRL) to:

- develop the necessary SOFC technologies to permit the utilization of defense logistic fuels including the assembly and testing of prototype fuel processing devices
- research and document the technical specifications for military applications
- gather information on performance requirements and use this information to drive the system design and development
- assemble and test prototype SOFC units.

This initial stage of research was required to develop military requirements for a SOFC power system that will address DOD needs.

Objective

This objectives of this work, which represents a first step in the development of military SOFC technologies, were to:

1. Identify the military's current and future electric power needs and capabilities
2. Identify the current and new requirements for mobile electric power systems and make design recommendations for building a military SOFC power system.

Approach

This work derived existing military electric power systems characteristics, future military electric power systems requirements, design considerations and recommendations, and a potential modularization plan from site visits, interviews, and (paper document and WWW) literature searches. Specifically, the research team:

1. Visited several DOD facilities and reviewed relevant documents i.e., military regulations, standards, specifications, etc. (Chapter 2)
2. Reviewed existing military electric power systems and military applications within each power class from 2 through 60 kW (Chapter 3)
3. Identified future military electric power systems, applications, and requirements based on information from PM-MEP and the Tactical Electrical Power Operational Requirements Document (TEP ORD) (Chapter 4)
4. Identified and provided design considerations to be addressed in the early design stage of a SOFC power system (Chapter 5)
5. Reviewed current mobile electrical power capabilities, provided high-level considerations for a modularization plan, and identified several potential benefits of a modularization plan (Chapter 6)
6. Identified an initial approach to a Modularization Plan for developing military SOFC technology that will minimize procurement, training, and maintenance costs.

Mode of Technology Transfer

It is anticipated that the information developed in this stage of work will support the CERL program to design, develop, and fabricate a military SOFC Power Plant up to 10 kW for military applications, which will include military diesel and JP-8 fuel reforming. The information in this report will be transmitted directly to the sponsor of this work, and will also be made accessible through the World Wide Web (WWW) at URLs:

http://www.cecer.army.mil (ERDC-CERL website)
http://www.dodfuelcell.com (DOD Fuel Cell Demonstration website).

2 Research Approach

Figure 1 illustrates the methodology used here to identify requirements, and to develop the capabilities summary and modularization plan. Military requirements were derived from interviews, technology reviews, literature searches, and follow-on analyses. Although an in-depth search of the www.assist.daps.dla.mil web site for SOFC Military Standards, Specifications, and Handbooks yielded no directly related documents, MEP information was readily available on various DOD Web sites. This information was supplemented with direct contact with user groups and procurement agencies.

Site Visits

Five on-site fact-gathering meetings were held at two installations to help identify military requirements. Meeting discussions included overviews of *CTC*, the DOD's Fuel Cell Test and Evaluation Center (FC*Tec*) operated by *CTC,* and the SOFC development project.

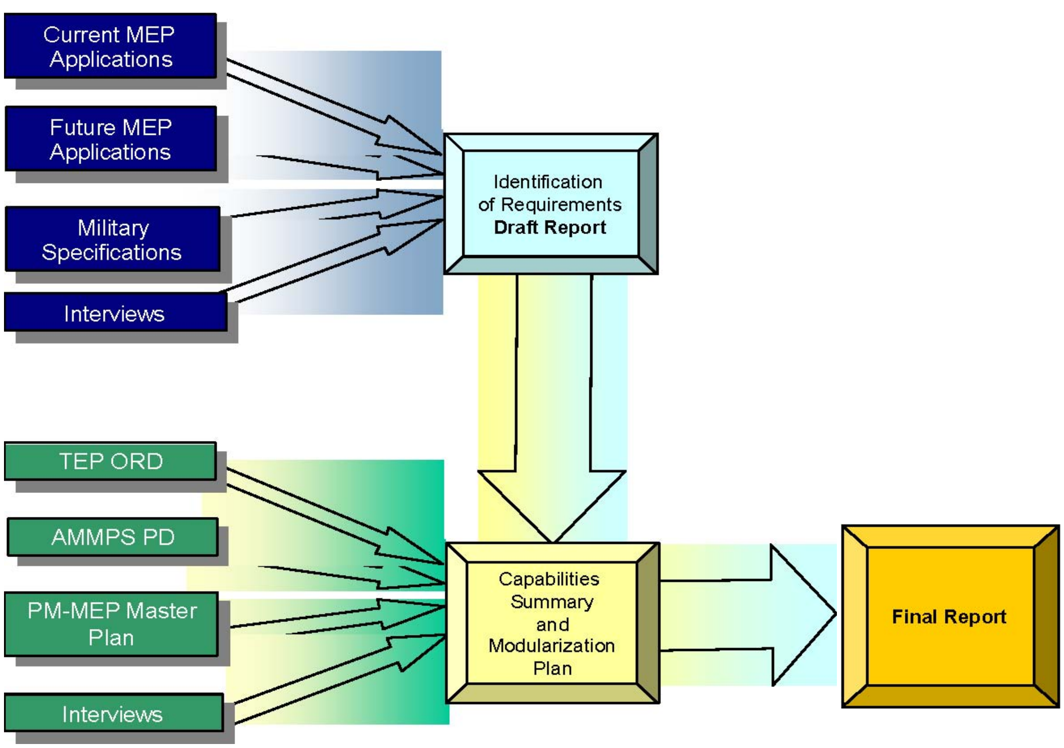


Figure 1. Information flow.

The MEP Tactical Quiet Generator (TQG) current capabilities were discussed with personnel at Warner Robins Air Logistic Center (WR-ALC) during the 3 June 2004 meeting. It was found that the end users and logistic centers do not have records of the total TQG capability. (The WR-ALC maintains records of the capabilities for the MEP within their command.) The PM-MEP procures and maintains records of the total MEP capability; TQGs are now being replaced by smaller, quieter, more efficient Tactical Electric Power (TEP). This information formed the basis for discussions with additional personnel of the PM-MEP (Table 1).

The primary focus of the meeting with PM-MEP personnel (Table 2) was to identify the military requirements. Secondary discussions focused on current and future MEP capabilities. The PM-MEP confirmed that TQGs are going to be replaced by TEP starting approximately 2007. The "TEP ORD, Advanced Medium-Sized Mobile Power System (AMMPS) Purchase Description," and "PM-MEP Master Plan" were discussed, and found to be useful sources of information to help identify the military requirements for future electrical power systems.

Table 1. Warner-Robins Air Logistics Center.

Meeting No.	Contact
1	Marianne Deuster, Division Chief
1	Barbara Schlafer, Branch Chief-Vehicles
1	Doug Foster, Branch Chief-Generators
2	Bill Likos, A_2PT_2O
3	Don Maycroft, Bear Base
4	Lisa Hosecloth, Program Manager for Generators
4	Tahrea Grant, Engineer
4	Nhat Nguyen, Lead Engineer
4	Gene Moss, Equipment Specialist

Table 2. Fort Belvoir meeting.

Meeting No.	Contact
5	Dr. James Cross, Deputy Program Manager
5	Kelly Alexander, Chief Engineer PM-MEP2
5	Paul Shively , Chief-Power Generation Branch
5	Walter Taschek, Fuel Cell Technology Team Consultant

Informational Documents

In-depth searches on the World Wide Web and meetings yielded several sources of information (Table 3).

Table 3. Informational documents.

Number	Document	Source
1	*Standard Family of Mobile Electric Power Generating Sources*	www.pm-mep.army.mil
2	*2 kW Military Tactical Generator Sets*	www.pm-mep.army.mil
3	*3 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
4	*5 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
5	*10 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
6	*15 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
7	*30 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
8	*60 kW Tactical Quiet Generator Sets*	www.pm-mep.army.mil
9	Military Standard, Specifications, and Handbooks	www.assist.daps.dla.mil
10	*PM-MEP Master Plan 2001*	PM-MEP
11	*Purchase Description Advanced Medium Sized Mobile Power Sources*	PM-MEP
12	Tactical Electrical Power Operational Requirements Documents (TEP ORD)	PM-MEP
13	*Advanced Power Generation Systems for the 21st Century: Market Survey and Recommendations for a Design Philosophy*	Oak Ridge National Laboratory

PM-MEP Documents

Table 4 lists the documents obtained from the PM-MEP to support this study.

Table 4. Documents obtained from the PM-MEP.

No.	Document	Source
1	*PM-MEP Master Plan 2001*	PM-MEP
2	*Purchase Description Generator Sets, Skid Mounted, Trailer Mounted Advanced Medium Sized Mobile Power Sources, Tactical*	PM-MEP
3	*Tactical Electrical Power Operational Requirements Documents*	PM-MEP

The *PM-MEP Master Plan 2001* provides PM-MEP's plan for attaining goals and how the vision will positively affect the U.S. Armed Forces. The primary focus reaps the benefits of standardization, which include: reduced number of configurations, reduced total operating costs, consolidated annual procurements, improved readiness, enhanced operation, maintenance and training, commonality of components, reduced number of operator and maintenance manuals, increased reliability, survivability, deployability, supportability, and warfighting effectiveness.

The document *Purchase Description Generator Sets, Skid Mounted, Trailer Mounted Advanced Medium Sized Mobile Power Sources, Tactical* provides general require-

ments for generator sets that are 5 through 60 kW, 50/60 and 400 hertz, skid mounted, trailer mounted, tactical, quiet, alternating current, and diesel fuel driven.

The document *Tactical Electrical Power Operational Requirements* describes the operational capability, threat, shortcomings of existing systems, capabilities, program support, force structure, schedule considerations, and program affordability.

3 Existing Military Electric Power Systems

This chapter identifies the applications and defines general characteristics for the existing military mobile electrical power systems. The primary information presented in this section was obtained from the PM-MEP Project Office.

The current families of military electrical power systems (2 through 60 kW) account for 100,691 individual units with a combined generating capacity of 1,037,725 kW. Table 5 lists individual units per kW classes. These systems were developed in the 1980s and their production is planned to continue through 2008. These power systems replaced the older MIL-STD family and provide significant improvements in mobility, supportability, survivability, and reliability. The 5 kW through 60 kW systems meet the current military needs, but will not comply with pending USEPA regulations and requirements. Manufacturers are anticipated to cease making non-compliant engines to replace engines in the current generator fleet. Consequently, these systems will become unsupportable as they age and as manufacturers stop making the necessary spare parts (reference TEP ORD 3.1.1).

Table 5. Current DOD electrical power system inventory.

Unit Rating (kW)	No. of Individual Units	Total Capacity (kW)
2	10,979	21,958
3	39,789	119,367
5	17,603	88,015
10	13,745	137,450
15	5,411	81,165
30	6,669	200,070
60	6,495	389,700
Total	***100,691***	***1,037,725***

Applications

Table 6 lists the primary applications and power classes (kW) provided by the PM-MEP Program Office for existing military electrical power systems.

Table 6. Applications of mobile/tactical electrical power.

Power Class (kW)	Primary Applications
2	Missile air defense systems, mobile kitchen units, combat support systems, communications systems
3	Weapon systems, missile systems, causeway systems, C4I systems
5	Weapon systems, missile systems, causeway systems, C4I systems
10	Weapon systems, missile systems, laundry units, C4I systems, refrigeration systems
15	Weapon systems, missile systems, well kit, printing plant, topographic support systems, C4I systems, hospital maintenance
30	Weapon systems, missile systems, bakery plant, and support systems, water purification, C4I systems, aviation shop sets
60	Weapon systems, missile systems, earth satellite terminals, field hospitals/schools, aviation ground support

Characteristics

Table 7 lists the physical characteristics and general capabilities of the existing 2 and 3 kW military electrical power systems (shown in Figure 2). The quantities listed are current totals. No future acquisitions are planned.

Table 7. Characteristics and capabilities 2 and 3 kW systems.

Characteristics	2 kW	3 kW
Model number	MEP -531A	MEP -831A
Voltage connection	120 VAC, single phase, 2 wire	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire
Frequency	50/60 Hz	50/60 Hz
Physical dimensions L X W X H (in.)	29.5 x 16 x 21.8	29.5 x 16 x 21.8
Weight (lb)	158	325
Total quantity (2004)	10,979	39,789
Reliability (hrs)	818	350
Fuel storage capacity (gal)	1.6	4
Fuel type	Diesel DL-1, DL-2, JP-8, Jet A-1	Diesel DL-1, DL-2, JP-8, Jet A-1
Fuel consumption (gal/hour)	0.33	0.33
Noise (dBa @ 7m)	79	79
Applied standards	EMI:* Suppressed to MIL-STD 461 limits EMP: None Human Factors: None	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169 Human Factors: MIL-STD 1474
* Electro Magnetic Interference (EMI)		

2 kW system

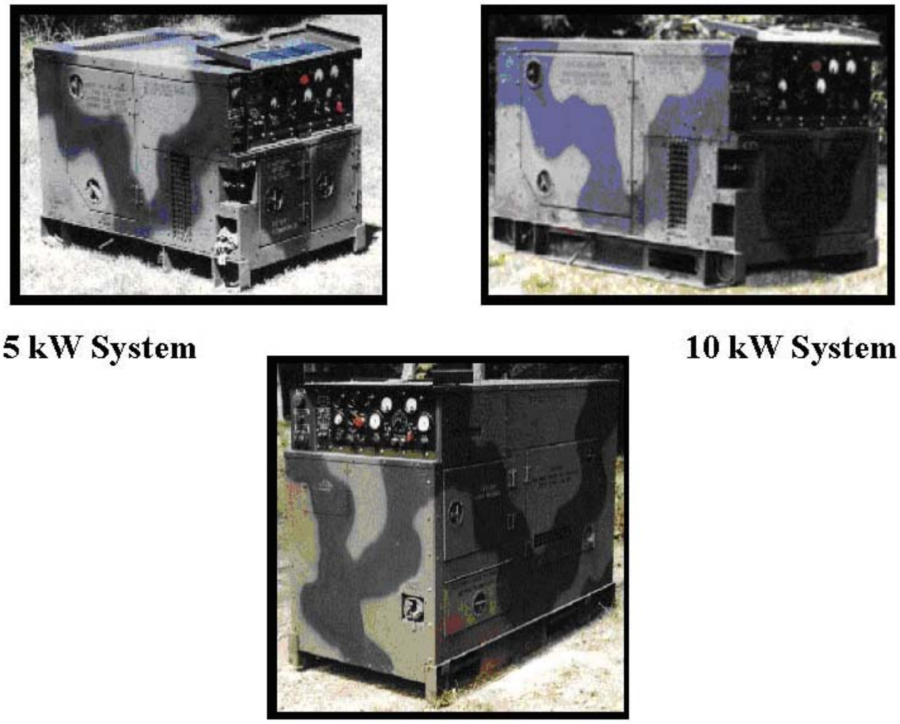
3 kW system

Figure 2. Electrical power systems (2 and 3 kW).

Table 8 lists the physical characteristics and general capabilities of the existing 5 kW, 10 kW, and 15 kW military electrical power systems (shown in Figure 3), along with current and future quantities with planned delivery for 1Q FY07.

Table 8. Characteristics and capabilities of 5, 10, and 15 kW systems.

Characteristics	5 kW	10 kW	15 kW
Model Number	MEP -802A	MEP -803A	MEP -804A
Voltage connection	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire 120/208, three phase, 4 wire	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire 120/208, three phase, 4 wire	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire
Frequency	50/60 Hz	50/60 Hz	50/60 Hz
Physical dimensions L x W x H (in.)	50.4 x 31.8 x 36.2	61.7 x 31.8 x 36.2	69.3 x 35.3 x 54.1
Weight (lb)	888	1182	2124
Total quantity (2004)	17,603	13,745	5,411
New system			
Deliver date & quantity	1QFY07 9,581units	1QFY07 5,846 units	1QFY07 2,777 units
Reliability (hrs)	442	600	538
Fuel storage capacity (gal)	5.0	9.0	14
Fuel type	Diesel DL-1, DL-2, JP-8, Jet A-1	Diesel DL-1, DL-2, JP -8, Jet A-1	Diesel DL-1, DL-2, JP-8, Jet A -1
Fuel consumption (gal/hour)	0.57	0.98	1.5
Noise (dBa @ 7m)	70	70	70
Applied standards	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169 Human Factors: MIL-STD 1472, MIL-STD 1474	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169 Human Factors: MIL-STD 1472 MIL-STD 1474	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169 Human Factors: MIL-STD 1474



5 kW System

10 kW System

15 kW System

Figure 3. Electrical power systems (5, 10, and 15 kW).

Table 9 lists the physical characteristics of 30 kW and 60 kW TQGs (shown in Figure 4), along with current and future quantities and planned delivery for 1Q FY07.

Table 9. System characteristics and capabilities of 30 kW and 60 kW TQGs.

Characteristics	**30 kW**	**60 kW**
Model number	MEP -805A	MEP -806A
Voltage connection	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire
Frequency	50/60 Hz	50/60 Hz
Physical dimensions LxWxH (in.)	79.3 x 35.3 x 54.1	86.3 x 35.3 x 58.2
Weight (lb)	3006	4063
Total quantity (2004)	6,669	6,495
New system deliver date & quantity	1Q FY07 3,678 units	1QFY07 3,966 units
Reliability (hours)	600	488
Fuel storage capacity (gal)	23	43
Fuel type	Diesel DL-1, DL-2, JP-8, Jet A-1	Diesel DL-1, DL-2, JP-8, Jet A-1
Fuel consumption (gal/hour)	2.43	4.51
Noise (dBa @ 7m)	70	70
Applied standards	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169 Human Factors: MIL-STD 1474	EMI: Suppressed to MIL-STD 461 limits EMP: HAEMP IAW MIL-STD 2169| Human Factors: MIL-STD 1474

30 kW System 60 kW System

Figure 4. Electrical power systems (30 and 60 kW).

4 Future Military Electric Power Systems

This chapter identifies the applications and defines the requirements for future military systems for mobile electric power. The primary information presented in this section was obtained from the MEP Project Office, PM-MEP Master Plan 2001 and the TEP ORD. Future electrical power systems, including SOFC power systems, are expected to comply with the applications and requirements presented here.

The MEP Project Office continuously coordinates with each service component during day-to-day operations leveraging diverse expertise to help determine the electrical power needs of future forces. The MEP Project Office also maintains close contact with the research and development community to ensure that the most promising technologies are identified, monitored, tested, and appropriately analyzed for adaptation to mobile electric power programs at the appropriate opportunity. The PM-MEP Master Plan 2001 was developed to inform its customers and partners of the multi-service Mobile Electric Power Generating Sources (MEPGS) fleet, and the Mobile Electric Power Generating Office. The information in the Master Plan report includes the present status and future plans for procurement and technology integration opportunities. The TEP ORD document contained information and requirements in general for future electrical generators (categorized as TEP). The TEP ORD document was drafted to be neutral prime mover, and to only identify the requirements of future military electrical power systems.

Applications

Table 10 lists the various applications of the DOD Total Force and power classes (kW) for future military mobile electrical power systems. The desired end state is to have a continuously ready, fully modernized, highly mobile, deployable fleet of electric power generators supporting these applications. In general, the data in Table 10 show that combat and communication systems will be powered by 2 kW power systems. Three kW to 60 kW power systems will be used to energize missile and weapon systems; small facilities will be powered by 30 kW to 60 kW systems.

Table 10. Applications of mobile/tactical electrical power.

Applications	Power Class (kW)						
	2	3	5	10	15	30	60
Mobile kitchen units	X						
Combat support systems	X						
Communications systems	X						
Missile systems	X	X	X	X	X	X	X
Causeway systems		X	X				
C4ISR systems		X	X	X	X	X	
Weapon systems		X	X	X	X	X	X
Laundry units				X			
Refrigeration systems				X			
Well kit					X		
Printing plant					X		
Topographic support systems					X		
Hospital maintenance					X		
Bakery plant						X	
ADP support systems						X	
Water purification						X	
Aviation shop sets						X	
Field hospitals/schools							X
Aviation ground support							X
Earth satellite terminals							X

Requirements

The following sections present the requirements for military electrical power systems defined by the TEP ORD.

Military Specifications, Standards, and Handbooks

Newly developed and future electrical power system performance should be evaluated by applying the test methods and procedures contained in the applicable Military Standards, Specifications, and Handbooks. Several Military Specifications, Military Standards, and Handbooks now in use and identified in the TEP ORD are applicable to electrical power systems. Although the primary focus of this work is on electrical power systems less than 50 kW, the current Military Specifications and Military Standards in use govern all power ranges. No specific SOFC Military Standards/Requirements currently exist, nor are any planned. The military plans to purchase electrical generators meeting or exceeding requirements established in existing ORDs and to remain neutral on the specific technology that provides the end effect, which is the supply of conditioned, mobile electrical power service.

Table 11 lists all of the Federal and Military Specifications identified in the Operational Requirements Document for military mobile electrical power, including whether the Specification is applicable to the development of a SOFC system for military applications. Appendix A gives additional details of each specification.

Table 11. Federal and military specifications.

Specifications		**Applicable to SOFC**	
		Yes	**No**
Federal			
A-A-52557	*Fuel Oil, Diesel; for Posts, Camps, and Stations*	X	
A-A-52624	*Antifreeze, Multi Engine Type*	X	
A-A-55804	*Rod, Ground (with Attachments)*	X	
A-A-59616	*Pipe Fittings: Bushings, Locknuts, and Plugs; Iron, Steel, and Aluminum; (Threaded); 125-150 Lb*	X	
Military			
MIL-PRF-2104	*Lubricating Oil, Internal Combustion Engine, Combat/Tactical Service*		X
MIL-PRF-2105	*Lubricating Oil, Gear, Multipurpose (Metric)*		X
MIL-DTL-5624	*Turbine Fuel, Aviation, Grades JP-4, JP-5*	X	
MIL-PRF-10924	*Grease, Automotive and Artillery*	X	
MIL-PRF-21260	*Lubricating Oil, Internal Combustion Engine, Preservative Break-In*		X
MIL-S-22473	*Sealing, Locking, and Retaining Compounds: (Single Compound)*	X	
MIL-PRF-46167	*Lubricating Oil, Internal Combustion Engine, Arctic*		X
MIL-A-53009	*Additive, Antifreeze Extender, Liquid Cooling Systems*	X	
MIL-C-53072	*Chemical Agent Resistant Coating (CARC) System Application Procedures and Quality Control Inspection*	X	
MIL-DTL-64159	*Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant*	X	
MIL-DTL-83133	*Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8 + 100*	X	
MIL-L-85762	*Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible*	X	

Table 12 lists all of the Federal and Military Standards identified in the Operational Requirements Document for Tactical Electric Power, including whether the Standard is applicable to the development of a SOFC system. Appendix B gives brief descriptions of each standard.

Table 12. Federal and military standards.

Standards		Applicable to SOFC Yes	No
Federal			
FED-STD-595	*Colors Used in Government Procurement*	X	
Military			
MIL-STD-130	*Identification Marking of U.S. Military Property*	X	
MIL-STD-209	*Lifting and Tie Down Provisions*	X	
MIL-STD-461	*Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems And Equipment*	X	
MIL-STD-705	*Generator Sets, Engine-Driven, Methods of Tests and Instructions*	X	
MIL-STD-810	*Environmental Engineering Considerations and Laboratory Tests*	X	
MIL-STD-814	*Requirements for Tie Down, Suspension and Extraction Provisions on Military Materiel for Airdrop*	X	
MIL-STD-882	*System Safety*	X	
MIL-STD-889	*Dissimilar Metals*	X	
MIL-STD-913	*Requirements for the Certification of Sling Loaded Military Equipment for External Transportation by Department of Defense Helicopters*	X	
MIL-STD-1472F	*Human Engineering*	X	
MIL-STD-1553	*Digital Time Division Command/Response Multiplex Data Bus*	X	
MIL-STD-2169B	*High Altitude Electro-Magnetic Pulse Environment (Secret)*	X	

Table 13 lists all of the Military Handbooks identified in the Operational Requirements Document for Tactical Electric Power. The table indicates if the Military Handbook is applicable to the development of a SOFC system. Appendix C briefly describes each handbook.

Table 13. Military handbooks.

Military Handbooks		Applicable to SOFC Yes	No
MIL-HDBK-705	*Generator Sets, Electrical, Measurement, and Instrumentation Methods*	X	
MIL-HDBK-784	*Guidelines—Design To Minimize Contamination and To Facilitate Decontamination of Military Vehicles and Other Equipment: Interiors And Exteriors*	X	
MIL-HDBK-810	*Environmental Engineering Considerations and Laboratory Tests*	X	
MIL-HDBK-831	*Preparation of Test Reports*	X	
MIL-HDBK-1791	*Designing for Internal Aerial Delivery in Fixed Wing Aircraft*	X	

Physical Characteristics

This section presents the physical requirements for future military electric power systems. The system characteristics are broken down to system size defined as cu-

bic feet and system deployed weight. Table 14 lists the characteristics, which are a collection of information defined by the TEP-ORD.

Table 14. Physical characteristics defined by the TEP-ORD.

Power Class (kW)	Threshold System Volume (cu ft)	Objective System Volume (cu ft)	Individual Deployed Weight (lb)
2 or less	5.4	4.5	142
3	13.35	11.12	292
5	30.6	25.5	799
10	36.9	30.8	1064
15	69.3	57.8	1975
30	79.2	66.0	2705
60	92.7	77.3	3657

Performance Characteristics

Table 15 lists performance characteristics, which are a collection of information defined by the TEP-ORD. The system characteristics are broken down into various areas considered performance related characteristics, threshold, and objective values. Columns 6 and 7 ("Threshold Probability Without Essential Function Failure," and "Objective Probability Without Essential Function Failure") indicate anticipated percentage and hours of operation of the systems without failure.

Fuels, Lubricants, and USEPA Compliance

Future military electric power systems are required to use jet propulsion fuels (JP-8) as the primary fuel. Similar military diesel fuels may be used to provide more flexibility to the commander. An impermanent performance degradation of 20 percent is acceptable when fuels other that JP-8 are used. This approach is consistent with the "single fuel on the battlefield" logistics policy. Additionally, compliance with USEPA emission regulations is a DOD policy.

Voltage and Frequency Output Characteristics

This section presents the alternating current (AC) electrical output voltage and frequency characteristics broken down by output kW rating vs. the needed voltage output. In summary, all future electrical power systems 3 kW and greater are required to have multiple voltage output ranges. Systems greater than 10 kW are required to have multiple switch selected frequency outputs (Table 16).

Table 15. Performance characteristics defined by the TEP-ORD.

Power Class (kW)	Fuel Type	Fuel Consumption (gal/hr)	Threshold Acoustic Signature (dBa @ 7m)	Objective Acoustic Signature (dBa @ 7m)	Threshold Probability Without Essential Functions Failure (% @hrs)	Objective Probability Without Essential Functions Failure (%@ hrs)	Threshold Repair Median Time (hrs)	Objective Repair Median Time (hrs)	Threshold Repair Maximum Time (hrs)	Objective Repair Maximum Time (hrs)
≤ 2	JP-8 & Diesel	0.28	72	69	91% @ 71	91% @ 118	1.5	0.5	2	1
3	JP-8 & Diesel	0.28	67	64	91% @ 71	91% @ 118	1.5	0.5	2	1
5	JP-8 & Diesel	0.48	68	65	91% @ 71	91% @ 118	1.5	0.5	2	1
10	JP-8 & Diesel	0.82	68	67	91% @ 71	91% @ 118	1.5	0.5	2	1
15	JP-8 & Diesel	1.22	70	67	91% @ 71	91% @ 118	1.5	0.5	2	1
30	JP-8 & Diesel	2.07	70	69	91% @ 71	91% @ 118	1.5	0.5	2	1
60	JP-8 & Diesel	3.83	72	69	91% @ 71	91% @ 118	1.5	0.5	2	1

Table 16. Electrical output characteristics.

Power Class (kW)	Voltage Output	Frequency
2 or less	120 VAC, single phase, 2 wire	50/60 Hz operation
3	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire	50/60 Hz operation
5	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire 120/208, three phase, 4 wire	50/60 Hz operation
10	120 VAC, single phase, 2 wire 120/240 VAC, single phase, 3 wire 120/208, three phase, 4 wire	50/60/400 Hz operation
15	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire	50/60/400 Hz operation
30	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire	50/60/400 Hz operation
60	120/208 VAC, three phase, 4 wire 240/416 VAC, three phase, 4 wire	50/60/400 Hz operation

Operational and Safety Features

All future electrical power systems for military applications are required to include safety and operation requirements (obtained from the TEP ORD). They must:

- Include the integration of safety devices to shut the system down automatically in the event of low fuel, high temperature, or voltage anomalies.
- Include a detection and warning system to alert personnel to conditions outside the normal operating parameters that could cause a hazard.
- Be designed to prevent errors in assembly, installation, or utility connection.
- Prevent the build up and release of energy, electrical or mechanical, through the use of fuses, relief valves, and electrical explosion proofing where applicable.
- Prevent the propagation of damage, in the event of a system component failure, from one component to another.
- Adhere to system design such the few or no special tools will be required to perform most field maintenance.
- Allow for enough on-board fuel to operate at 75 percent output capacity for at least 8 hours and for the connection of an external fuel tank to extend the operating time.
- Use plugs and quick disconnect connectors, so long as it does not affect the reliability of the system.
- Provide status indicators for fuel, temperature(s), pressure(s), frequency, voltage, etc., that can be read both day and night.
- Identify and indicate maintenance functions and problems and aid the maintenance performers in diagnosing and identifying modules and components for replacement.
- Allow the system to operate at any orientation on uneven terrain with grades of up to 15 degrees in all angles.

- Allow for the system to operate at full rated load in tropical, temperate, arid and cold climates. The system must also operate at full output at 95 °F and 4,000 ft above sea level, and standard de-rated output at 95 °F and 10,000 ft above sea level.
- Allow for the automatic parallel operation of systems of like size and operational mode for systems 10 kW and larger
- Include a standard NATO slave receptacle, which would allow personnel to connect a military vehicle 24 VDC system to the SOFC system in the event of dead start-up batteries.
- Allow for open-air or warehouse storage.
- Start and accept full load within five (5) minutes for all systems excluding technologies that require lengthy start up times and procedures.
- Operate as designed when covered with infrared suppression nets.

Environmental Requirements

MIL-STD-810 defines procedures for determining and assessing the diverse environments to which military systems will be exposed during its service life. Table 17 lists the environmental requirements and variables contained within this specification that are applicable to future military electrical power systems. MIL-STD-810 references additional information on methods developed to support accurate determination of the environmental stresses that equipment will encounter during its service life and to verify corrective actions. Note: the variables listed in Table 17 are “worst case” and do not necessarily apply to all articles being evaluated. Considerations for individual articles need to be applied as indicated in MIL-STD-810.

Table 17. Environmental requirements.

Requirement Name	Description	Variable 1	Variable 2
Low pressure (altitude)	Ground use altitude Air transport altitude Explosive decompression Rapid decompression	4,570 m 0 m to 4,572 m 2,438 m to 0 m 2,438 m to 0 m	None Rate of climb 10 m/s Rate to decompress 0.1 s or less Decompression rate 15 s
High temperature	Basic hot Hot	Ambient air 86 °F –110 °F Ambient air 90 °F – 120°F	Ambient air 86°F – 145°F Ambient air 91°F – 160°F
Low temperature	Evaluate effects during storage and operation	Temperature based on requirements documents or where the unit will be used	Minimum 72 hrs for longest test
Temperature shock	Hot to cold Cold to hot	Temperature shock range determined by lengthy process	N/A
Solar radiation (sunshine)		1120 W/m^2 and 49 °C (120 °F)	Test length 56 24-hr cycles or longer
Rain	Maximum rate and size noted in standard	4 in./hr	Droplet size up to 0.1772 in.
Humidity	Start temperature and RH End temperature and RH	73.4 °F @ 50 % RH 86 °F @ 95 % RH	N/A
Fungus	U.S. And European groups of fungus commonly used for testing	*Aspergillus niger, Aspergillus terreus, Paecilomyces varioti, Penicillium funiculosum, Penicillium ochro-chloron, Scopulariopsis brevicaulis, Aspergillus flavus, Aspergillus versicolor, Penicillium funiculosum, Chaetomium globosum, Trichoderme Viride*	Minimum 28 days and up to 84 days for added certainty
Salt fog	Salt solution	Unless otherwise identified, use a 5 +/-1% salt solution concentration	Two wet and two dry periods each 24 hrs in length
Sand and dust	Blowing dust particle Blowing sand	< Or = 149 µm 150 to 850 µm	1750 ft/min 5700 ft/min

Requirement Name	Description	Variable 1	Variable 2
Explosive atmosphere	Demonstrate the ability of material to operate in fuel-air explosive atmospheres without causing ignition, or demonstrate that an explosive or burning reaction occurring within encased equipment will be contained, and not propagate outside the test item.	95% n-Hexane with 5% Other Hexane Isomers	N/A
Leakage (immersion)	Immersion Partial immersion	Complete Depth not specified	30 minutes
Acceleration	Air carried stores	2 Inertia Load (g)	N/A
Vibration	Truck, trailer, tracked vehicle, jet aircraft, propeller aircraft, helicopter, surface ship, train	Vibration set points dependent upon type of test and the physical attributes of the system to be tested	Length of test is dependent upon the type of test being conducted
Acoustic noise	Noise environment effects	10 Hz to 10,000 Hz Various amplitudes	Test duration determined through lengthy procedure
Shock	Evaluation of expected shocks during service life	Up to 10,000 Hz	Duration up to 1 second
Gunfire	Random vibration energy	DC to 2kHz	
Temperature, humidity, vibration, altitude	Qualification test	Use parameters listed in temperature, humidity, vibration, altitude methods	N/A
Icing/freezing rain	Rime ice Glaze ice	0.2 g/cm^3 to 0.9 g/cm^3 0.9 g/cm^3	Ice thickness up to 75 mm
Vibro-acoustic, temperature	Externally carried aircraft stores during captive carry flight	Variables for vibration, acoustics, and temperature are determined through a lengthy process	N/A

Daily Operational Profiles

Tables 18 to 21 list predictable profiles for electric power systems 60 kW and under during operational missions. The various tasks within the profiles include Preventive Maintenance Checks and Services (PMCS), operating load percentages and non-operational time for movement of the system. For reference, the PMCS is to coincide with system fueling normally every 8 hours. Provisions for the transportation of electrical power systems are detailed in Mil-STD 209, MIL-STD 814, MIL-STD 913, and MIL-HDBK-1791. Appendix A to this report gives a short description for each document. Federal Specification A-A-55804 details provisions for grounding the system.

Table 18 lists profile information for the 24-hr operation for military electric power systems, with a percentage of output delineation versus total time and total time to complete PMCS.

Table 18. Twenty-four hour operational profile during stationary days.

Tasks	Time (hrs)	Operational (%)	Non-Operational (%)
PMCS	0.33		1
80-100% load	4.6	19.17	
60-80% load	7.25	30.25	
40-60% load	7.25	30.25	
Less than 40% load	4.6	19.17	
Total Time	***24***	***99***	***1***

Table 19 lists profile information for 24-hr of operation for military electric power systems, with a percentage of output delineation versus total time, total time to relocate the TEP system and total time to complete PMCS.

Table 19. Twenty-four hour operational profile during movement days.

Tasks	Time (Hours)	Operational (Percent)	Non-operational (Percent)
PMCS	0.33		1
80-100% load	4	16.67	
60-80% load	6.33	26.37	
40-60% load	6.33	26.37	
Less than 40% load	4	16.67	
System movement	3		13
Percentage of total time		86	14
Total Time	***24***		

Table 20 lists data pertaining to a 15-day wartime Mission Profile (MP) with movement of the operation for a military electric power system every third day. The system is anticipated to be set up upon arrival and PMCS will be performed. The sys-

tem will then be operated for the remainder of that 24-hour period. Tables 18 and 19 provide a profile breakdown of the stationary and movement days. The system is anticipated to be relocated every 3 days to five different sites. The relocation is estimated to take 3 hours to complete over varied terrain. The relocation distance will typically be 18 to 135 miles; the 3-hour rule will not automatically apply to distances over 135 miles.

Table 20. Fifteen-day wartime mission profile tasks.

	Stationary Day (hrs)	Movement Day (hrs)	Total Days on Task	Total Hours on Task	Total Operating Time (hrs)
Operating stationary days	23.67		10	236.7	340
Operating movement days		20.67	5	103.3	
PMCS	0.33	0.33	15	5	
System movement		3	5	15	
Total Time	***24***	***24***	***15***	***360***	

Program Cost

The information presented in this section was obtained from Section 8.0.2 TEP ORD. Table 21 lists the estimated program cost data for future procurement of military electric power systems. This information is based on current projections derived from the existing military electric power system procurement program. This data is subject to change as the electrical program matures. The program cost is based on FY02 dollars for a 10-year, multi-phased modernization program with fielding planned from 2009 through 2019. Individual systems will have a designed service life of 15-20 years. These costs include research, development, engineering, testing, documentation, program management, procurement, training, and fielding.

Table 21. Electrical program cost estimate 2009 through 2019 power class.

Class	Average Unit Price	Quantity	Price Per kW	Total Cost (Thresholds)
5 kW	$14,375	8,950	$2,875	$128,656,250
10 kW	$16,675	8,247	$1,667	$137,518,725
15 kW	$19,264	3,230	$1284	$62,222,720
30 kW	$27,025	2,362	$900	$63,833,050
60 kW	$31,337	1,931	$522	$60,512,712
Totals		***24,720***		***$452,743,457***
FY08-FY18 Projected quantities and cost based on advanced medium-sized mobile power sources cost savings analysis (June 2002).				

If the Army does procure 24,720 electrical power systems, the cost savings exceed $131 million for a 10-year phased replacement period or about $330 million over the systems anticipated 17-year life cycle. This information is based on comparing data from military electric power system operations during peacetime (300 hours/year/set average) and wartime (4080 hours/year/set average). Given that 24,720 modernized

generators are procured that are 15 percent more fuel-efficient and 20 percent more reliable, these improvements are anticipated to yield the savings mentioned. This is based on an initial $30M Research Development Test and Evaluation (RDTE) investment; the return on investment (ROI) is about 4.5 years. These savings are combined with fielding modernized generators using advanced technology that will yield significant operational benefits (TEP ORD Resource Summary).

System Training Concept

The development and acquisition of future military electric power systems will require additional training for the Power Generation Equipment Repairer known as Military Occupational Specialty 52 (MOS 52) and their supervisors. It is anticipated that the existing Basic Noncommissioned Officer Course (BNCOC), Advanced Noncommissioned Officer Course (ANCOC), Warrant Officer Basic Course (WOBC), and Warrant Officer Advance Course (WOAC) will be enhanced to address future training requirements. The following guidelines for training on future electric power systems was obtained from the TEP ORD:

- Maintenance training will not impact manpower requirements.
- The Material Developer will provide a multimedia Training Support Package (TSP).
- Maintenance training will be provided by the Ordnance Mechanical Maintenance School (OMMS).
- Future electrical power systems will not require new MOSs and minimize any increase in system operational complexity or maintenance.
- The Material Developer will ensure that Test, Measurement and Diagnostic Equipment (TMDE) or any special tools are on hand for system fielding and for New Equipment Training (NET).

The future training concept indicates that it is the responsibility of the Material Developer to develop a comprehensive multimedia TSP and products to support all aspects of training on the future electrical power systems. It will also be the responsibility of the Material Developer to train instructors and key personnel.

The events and activities necessary for future training are defined in the Automatic System Approach to Training (ASAT) and are to be implemented in the development of the Training Plan. It will be the responsibility of the Material Developer to maintain and update the training materials throughout the life cycle of the system. The Material Developer will also monitor the institutional trainers and update the training program as needed.

5 Design Considerations and Recommendations

This chapter contains design considerations generated during the this study. Although these topics are not necessarily covered by the TEP ORD, they should however be considered during the early stages of designing the SOFC system. High-level design recommendations generated during this effort are also presented.

Design Considerations

This section describes several areas that should be considered during the design phase of the SOFC system including the possible need for water to operate, sulfur content in logistical fuels, and fuel additives that enhance fuel performance.

Water Availability

Fuel Cell Technology Team Consultant Walter Taschek stated that “Supplying water in the field will have a logistic impact not so much because it takes water away from the soldier, but that it must be provided and that it must be clean.” SOFC power systems requiring water to operate could negatively impact the logistical footprint reduction objectives of the TEP program. Therefore, SOFC systems will be much more attractive it they were self-sustaining and did not require water. Even if there was water available in the Area of Operation (AOR), equipment may be required to process the water so that it would be useable in the SOFC.

An existing Quadripartite Standardization Agreement (QSTAG) titled “QSTAG2028 ED.1 Bulk Water Supply on Extended Operations” is currently listed as the “Controlled Distribution Document.” (This document is not available to the general public.) The aim of this QSTAG is to agree on the minimum compatible doctrine for bulk water supply on extended operations.

Sulfur Content in Military Fuels

The Detail Specification of MIL-DTL-83133E covers three grades of kerosene type aviation turbine fuels consisting of NATO F-34 (JP-8), NATO F-35, and JP-8+100. The document states the maximum total sulfur content in percent mass is 0.30.

The Commercial Item Description (CID) for fuel oil and diesel suitable for use in ground compression-ignition and gas turbine engines and other diesel fuel consuming equipment provides information on two grade designations:

1. *Grade Low Sulfur No. 1-D*, which is a special-purpose, light distillate fuel used for automotive diesel and gas turbine engines requiring low sulfur fuel and requiring a higher volatility than that provided by Grade Low Sulfur No. 2-D.
2. *Grade Low Sulfur No. 2-D*, which is a general-purpose middle distillate fuel used for automotive diesel and gas turbine engines requiring low sulfur fuel. It is also suitable for use in non-automotive application. The Grade Low Sulfur has a sulfur level no higher than 0.05 percent by weight.

Under authority of the Clean Air Act, the USEPA issues limits on the maximum sulfur level, the maximum aromatic content or minimum cetane index on diesel intended for on-road use. According to the Clean Air Act, the sulfur content requirements for diesel fuel, effective 1 October1993, shall not exceed 0.05 percent concentration (by weight) or fail to meet a minimum cetane index of 40.

A caution on this subject of fuel sulfur content is that in a time of war, a commander will use the fuel that is available to him. Therefore, the fact remains that the sulfur content could be outside the above stated limits. The sulfur content of middle distillates depends on the source of crude oil. The sulfur content of some diesel fuels ranges from 0.01 to greater that 3 percent. It is not recommended that the SOFC system be designed to handle the worst scenarios, however it is recommended that options for future developments provide a reliable path forward.

Diesel Fuel and NATO F-34 (JP-8) Additives

Aviation fuel additives are fuel soluble chemicals added in small amounts to improve or maintain properties important to fuel performance or fuel handling. Typically, additives are derived from petroleum-based raw materials, and their function and chemistry are highly specialized. They produce the desired results in the parts per million-concentration range. One ppm is 0.0001 mass percent.

Military Detail Specification MIL-DTL-83133E defines F-34 (JP-8) as a kerosene type turbine fuel that contains a static dissipating additive, corrosion inhibitor/lubricity improver, and fuel system icing inhibitor and may contain antioxidant and metal deactivator.

Static Dissipater for JP-8

Jet fuel has poor electrical conductivity and can present potential safety hazards under certain conditions. Additives have been developed that improve the fuel conductivity and are referred to as static dissipaters.

A static dissipater additive is blended into the fuel in sufficient concentration to increase the conductivity of the fuel. The following electrical conductivity additive is approved: Stadis 450 marketed by Octel America, Inc., Newark, DE 19702. The data listed in Table 22 is compiled from information contained in the MSDS.

Table 22. Static dissipater composition, composition/ingredient information.

Material	Percent
Toluene	40-50
Benzene	<0.0595
Isopropyl alcohol	<5
NJ Trade Secret #35-1927749-5457	1 to 10
NJ Trade Secret #35-1927749-5037	10 to 20
Dinonylnaphthylsulfonic acid	5 to 15
Heavy aromatic naphtha.	15 to 25
Naphthalene	<3

Corrosion Inhibitor/Lubricity Improver for JP-8

The tanks and pipelines of the jet fuel distribution system are constructed primarily of uncoated steel. Corrosion inhibitors in jet fuel prevent free water and oxygen from rusting or corroding those structures.

A corrosion inhibitor is blended into the F-34 (JP-8) grade fuel. The amount added is equal to or greater than the minimum effective concentration and shall not exceed the maximum acceptable concentration. The recommended concentration for conventional use varies by manufacturer. The minimum effective concentration assumes g/m^3 is equivalent to parts per million by volume. Lubricity additives are used to improve lubricity in hydro-treated jet fuels. The lubricity improver adheres to metal surfaces forming a thin layer of the additive. This thin layer acts as a lubricant between two metal surfaces.

The minimum effective concentration shall be larger than the following:

- one and a half times the relative effective concentration, which is not less than 6 g of finished inhibitor per cubic meter of fuel (6 g/m^3), and not more than 36 $g/m^{3,}$ and shall be at a concentration divisible by 3 (i.e., 6, 9, 12, 15, … 36 g/m^3)
- the amount of inhibitor that gives a wear scar diameter of 0.65 mm or less when using the ball-on-Cylinder Lubricity Evaluator.

The maximum allowable concentration shall be the lowest of the following:

- 54 g/m^3
- four times the relative effective concentration, which is not less than 6 g of finished inhibitor per cubic meter of fuel (6 g/m^3) and not more than 36 g/m^{3,} and shall be at a concentration divisible by 3 (i.e., 6, 9, 12, 15, … 36 g/m^3)
- the highest concentration that results in Micro-Separometer rating of 70 or higher
- the highest concentration that results in a less than 40 percent change in electrical conductivity with fuel containing a static dissipater.

The National Stock Number for the corrosion inhibitor is 6850-00-292-9780 and was used to obtain a MSDS for the material. Table 23 lists MSDS information for corrosion inhibitor manufactured by UOP Inc., Des Plaines IL.

Table 23. Corrosion inhibitor composition, composition/ingredient information.

Material	Percent
Unsaturated Dimer Fatty Acid	40 to 70
Aromatic Solvent	Not Listed
Other Ingredients	Not Listed

Icing Inhibitor and Antioxidant for JP-8

At very low temperatures, ice can form in fuel tanks—especially at high altitude. This generally happens due to water that was dissolved in the fuel when the fuel tank was filled, which condenses as the temperature drops.

The use of a fuel system icing inhibitor is mandatory for NATO F-34 (JP-8) and shall conform to MIL-DTL-85470. The point of injection of the additive for NATO F-34 (JP-8) shall be determined by agreement between the Purchasing Authority and the supplier. The inhibitor shall be composed entirely of diethylene glycol monomethyl ether except that an antioxidant specified below is be added at a concentration from 50 to 150 parts per million by weight. The antioxidant shall be added immediately after processing and before the inhibitor is exposed to the atmosphere. The antioxidant added to the inhibitor shall be one of the following:

- 2,6 ditertiary butyl, 4-methylphenol
- 2,4 dimethyl, 6-tertiary butylphenol
- 2,6 ditertiary butylphenol
- Mixed tertiary butylphenol composition:
  - 75 percent, minimum, 2,6 ditertiary butylphenol
  - 25 percent, maximum, tertiary and tritertiary butylphenols.

Metal Deactivator for JP-8

Metal deactivators form stable complexes with metal ions that are effective catalysts for oxidation reactions like copper and zinc. These metals are not typically used in fuel systems, however, if the fuel becomes contaminated, metal deactivators inhibit their catalytic activity.

A metal deactivator may be blended into the fuel. The concentration of active material used on the initial batching of the fuel shall not exceed a concentration of 5.7 mg/L. Metal deactivator shall not be used in JP-8 unless the supplier is given written by the procuring agency or user.

According to Military Detail Specification MIL-DTL-83133E, the metal deactivator added to JP-8 is N,N'–disalicylidene-1,2-propanediamine.

CI Solvent Red 164 for Diesel Fuel

A confusing situation for both refiners and purchasers of diesel fuel has arisen because both the Internal Revenue Service (IRS) and the USEPA require the addition of red dye to certain classes of diesel fuel. However, each agency requires that the dye be added to a different class of fuel, at a different concentration, and for a different reason. The USEPA wants to identify diesel fuel with high sulfur content to ensure that it is not used in on-road vehicles. The IRS wants to ensure that tax-exempt low sulfur and high sulfur diesel fuel are not used for taxable purposes. The IRS regulations require that tax-exempt diesel fuels, both high sulfur and low sulfur, have a minimum level of a Solvent Red 164 dye that is spectrally equivalent 3.9 lb of the solid dye standard Solvent Red 26 per thousand barrels (bbl) or 11.1 mg/L of diesel fuel. This level of dye is more than five times the amount required by the USEPA regulations. The IRS contends that the high dye level is necessary to allow detection of tax evasion even after five-fold dilution of dyed fuel with un-dyed fuel.

According to the MSDS the ingredients are (no volume or percentage listed):
- 2-Napthalenol [(Phenylazo) phenyl]-Azo Alkyl Derivatives
- Benzene
- Ethyl Benzene
- Other absorbent materials.

Ground Fuel Additive to Optimize Lubricity

Paradyne 655 additive is manufactured by Exxon and used as a lubricity improver in ground fuels. It is used where severe wear problems exist and when fuel has been tested and found to have very low lubricity. The recommended concentration

is 80 ppm by volume, but can be increased to 200 ppm if needed. Paradyne 655 could not be found in any known MSDS resources or on the Exxon web site.

Ground Turbine or Diesel Stabilizer/Biocide

The diesel fuel stabilizer additive is used to prevent or slow the formation of deterioration products in ground fuels due to auto-oxidation and to eliminate microbiological growth. The system includes an antioxidant, metal deactivator, corrosion inhibitor, detergent dispersant and biocide. It is available in one and two package systems. The recommended concentration for the additives varies by manufacturer.

Design Recommendations

Most of the recommendations generated during this effort are "rule of thumb" items to consider during the initial design stages. (Some will require a detailed analysis.) One important thing to keep in mind is to allow for an iterative design approach that will allow technological improvements to be incorporated into the system throughout its life cycle.

Minimum Stack Voltage

The SOFC stack voltage, inverter input voltage, and the generator output voltage will have to be closely matched. Table 24 lists the minimum inverter input voltage that will be required for a specified generator output voltage based on a "rule of thumb" formula. If the stack is not capable of providing this minimum voltage, a DC/DC converter or boost transformer will be required to meet the inverter input voltage. Obviously, the addition of a DC/DC converter may increase the weight and volume of the system and reduce the overall efficiency of the system. A thorough trade off analysis would be required to determine the best approach for the system.

Table 24. DC inverter input voltage vs. generator output voltage.

Generator Output Voltage	Minimum Inverter Input Voltage
(VAC)	(VDC)
120	186
208	323
240	373

Operator Interface

Design a Human Machine Interface (HMI) that is universal to the generators of interest. Ensure that the system is expandable, and that, if possible, it uses a uni-

form control scheme, including layout and operation of switches, buttons, and system readouts.

Preventive Maintenance Checks and Services

The system should be designed for manufacturing, troubleshooting, and repair. Access to internal components should be easily accessible with removable side panels and top covers. Filters, fluid drains, and fluid fill caps should be easily accessible for PMCS.

Control System

When possible, design all control systems to use the same control methodology and electronic control components. Use the same sensors to monitor and control the system and provide safety. Scaling factors could be changed to meet the need of different power levels.

Improved Efficiency

Evaluate possible methods to improve overall system efficiency. There may be a break point at a certain power lever where it may make sense to incorporate cogeneration to take advantage of waste heat. This may also provide benefit in reducing the thermal signature of the system. A systems approach is recommended to investigate optimum operating ranges for all major subcomponents working in the system.

6 Modularization

This chapter discusses current mobile electrical power capabilities, provides high-level considerations for a modularization plan, and identifies several potential benefits of a modularization plan.

Capabilities Assessment

As mentioned in Chapter 3, the current inventory of electrical generators in the range of 2 kW to 60 kW account for 100,691 individual units. These systems will replace current generators on a one-for-one basis in an effort to replace obsolete systems that exceed their life expectancy, lower sustainment costs, meet USEPA requirements, and improve performance.

The Army's power system requirements represent approximately 75 percent of the total Services power system requirement. Table 25 lists the total Army requirements for power systems from 60 kW and below. In addition, there are approximately 20,300 power systems required from other Services in unspecified power ranges.

Table 25. Total Army generator requirement quantities power class.

Class	Generator Quantities
Under 5 kW	24,244
5 kW to 60 kW	37,694
Total	***61,938***

Historically, power systems are replaced at a rate of 2,500 per year. The Army requirements for power systems from power levels of 5 kW through 60 kW can be further distinguished (Table 26).

Table 26. Army requirement per year power class.

Class	Per Year Quantities
5 kW	895
10 kW	824
15 kW	323
30 kW	236
60 kW	193
Total	***2,471***

As the data in Table 26 suggest, the generators in the 5 and 10 kW power classes account for nearly 70 percent of the total Army per year requirements.

Modularization Approach

Many different aspects must be considered to develop a Modularization Plan. System cost, weight, volume, and efficiency are just a few topics that should be considered. Another important factor in the determination of a modularization approach is the technology used in the power system. The entry of SOFC technology in the early stages of its infancy is an ideal opportunity to take a “System of Systems” approach to develop and analyze the modularization plan. The development of a Modularization Plan and the complete analysis that is required to support the plan is beyond the scope of this task. However, the intent of this work is to provide discussions and considerations that will spawn a design approach that could benefit from a modularization plan. One of the assumptions that will be used is that the existing generator power classes will remain the same (i.e., 2, 3, 5, 10, 15, 30, & 60 kW). This is important to mention and to follow in the future based on conversations with Mr. Walter Taschek, Fuel Cell Technology Team Consultant at the PM MEP, who expressed the opinion that the current 5 kW and smaller generators should be matched for size, and that the military would benefit if there would be more generator size options in the 10 kW and larger size range.

Modularization Considerations

Based on the requirements for electrical power systems listed in Chapter 4, a majority of the units are in the power range from 10 kW and below. With limited knowledge of the exact power level listed in the “Under 5 kW” category, it is impossible to generate a plan without some speculation. Based on the existing systems, one can assume the military will continue to require 2 kW and 3 kW systems. However, there is hint in the TEP ORD that the range “Under 5 kW range” will include 0.5 kW through 3 kW.

Assume for a moment that the smallest power level required by the military was 2.5 kW and it is feasible to build a module at this power level, this could prove to be an ideal base module. Two modules could be combined for a 5 kW power system and four modules could be combined for a 10 kW power system.

Unfortunately, it is not that easy. Power density, weight, efficiency, all cost considerations, inverter requirements, system reliability, and DOD requirements will all need to be analyzed and given the appropriate consideration. The military is con-

tinually looking for electric power solutions that will reduce operations and sustainment costs, fuel usage, weight, acoustic signature and that will increase reliability and ease maintainability. Additionally, SOFCs are no different than any other technology in regards to the need to identify the niche market. Therefore, what makes sense from the technology must also be thoroughly considered.

One approach that could be taken for future activities is to develop a modularization plan based on technology (i.e., fuel cell, system components, and inverters) and assume that the DOD generator sizes will remain consistent with today's requirements. Nevertheless, it is recommended that any future development be coordinated with PM-MEP to remain on top the DOD's needs and requirements.

Based on the analysis, it may be determined that a 1 kW module size is the best choice based on power density, weight, efficiency, cost, and reliability. If this were the case, the 2, 3, 5, and 10 kW systems could be made up of 1 kW modules stacked together in a chassis. Standard chassis sizes for three and five modules could be used for all systems from 2 through 10 kW power systems. In this scenario, the 2 kW systems would have an empty slot and the 10 kW system would be made up of two, five-slot chassis.

To reap the benefits of a modulation plan, one must also consider the potential benefits in the design process. One should take advantage of mass production and the use of identical components to reduce training, maintenance, and logistics. One approach is to develop a decision matrix that lists all pertinent criteria by which alternatives will be assessed. Each alternative will be assessed against the stated criteria and assign a numeric value for each alternative's ability to meet the criteria. Stakeholders would be solicited to assign a weighting factor to each criterion to determine the level of importance. The solution with the highest score is the "winner."

Modularization Benefits

Several potential benefits could be realized from a modular approach to mobile electric power. The potential benefits could include reduce logistics, reduce system cost, and reduced training and maintenance. The identification of a common sized SOFC module could decrease the overall cost of fabrication through:

- bulk purchases of balance of plant components such as catalytic material, system pumps, sensors, readouts, solenoids, tubing, etc.
- mass production of the SOFC stack component, electronic control system, wiring harnesses, chassis, and reformer sections.

Reduction of Training and Maintenance Requirements

One benefit of adopting a modular approach to SOFC systems is the potential for reducing training and maintenance requirements. Reducing the medium generator fleet to a lesser quantity of SOFC module sizes means that technicians would require less classroom training and the users would need to keep fewer maintenance and replacement on hand. The standardization of the SOFC modules' control system will decrease the time needed to train and familiarize personnel with the equipment. The addition of controls to identify problems and indicate needed maintenance will help maintenance workers to reduce downtime and will alert operators to potential problems. Some of the training and maintenance benefits are :

- Training benefits:
  - Reducing the seven variations of medium power generating options would allow personnel to be trained more efficiently throughout the SOFC module range. Adopting a modular approach would allow personnel trained on the 1 kW module to be capable of working on 1 kW through 3 kW systems. The same would hold true for the 5 kW and 25 kW modules.
  - Using one control system while factoring in the necessary control differences for the different SOFC module sizes would promote the commonality of the SOFC systems and reduce the number of control systems personnel would need to be trained to operate, maintain and repair.
  - Developing inverters capable of producing the required voltage and frequency output would reduce the overall time needed to complete training across the generating fleet.
  - Standardizing the modular layout for the SOFC module sizes will decrease the time needed to train personnel on subsequent systems.
- Maintenance benefits:
  - Use of one control system that can be loaded with system specific parameters and set points will reduce maintenance inventory and increase the maintenance performers expertise.
  - Use of the same control sensors for all SOFC modules will reduce the maintenance inventory.
  - Use of the same controlled devices, where appropriate, will reduce the maintenance inventory.
  - Incorporating sensors into the control system will help identify problems needed maintenance, thereby reducing down time.
  - SOFC modules with removable side panels and top covers will permit straightforward PMCS and component replacement.

7 Conclusions

This work has identified Federal and Military Specifications, Standards, and Handbooks pertinent to the fielding of SOFCs into U.S. Services as a source of military power systems, and other documents that are pertinent to the development of SOFC military power systems (<60 kW) based on information gathered through assessments of current applications and procurement requirements for military electric power. Other information relevant to SOFC military power systems development was gathered from discussions with user groups and procurement agencies, research via various DOD Web sites, and two off-site meetings held with leadership level personnel at WR-ALC and PM-MEP at Fort Belvoir.

This work has shown that the current inventory of MEP within the 2 kW to 60 kW range, accounts for 100,691 individual units with a combined generating capacity of 1,037,725 kW. The total inventory will be expanded by 25,848 individual units by the end of 1QFY07. Although the TQG family does meet current military needs and production will continue through 2008, it will not comply with pending USEPA regulations. Furthermore, engine manufacturers will cease production of non-compliant replacement engines for the current generators, which will eventually render the current MEP fleet obsolete.

The goal of the PM-MEP is to field systems to replace the obsolete systems exceeding their life expectancy by 5 years, lower sustainment costs, meet USEPA requirements and improve performance. It is estimated that the Army will procure an initial quantity of 24,720 medium output systems over a 10-year period. During this time, existing generators will be replaced with future electric power systems, which will be characterized by:

1. Reduced weight and footprint requirements enhancing deployment throughout the generator spectrum.
2. Increased fuel efficiency, which will reduce fuel tanker fleet size and further decrease the logistical footprint
3. Ability to meet stringent “Mean Time Between Failure” probability goals to operate without an essential function failure
4. Ability to meet median and maximum repair times for unscheduled maintenance to ensure reliability and not adversely affect mission critical C4ISR systems.

This study has compiled predictable daily operating profiles for future electric power systems 60 kW and below during operational missions, including PMCS, op-

erating load percentages, and non-operational time for movement of the system, including a 15-day wartime Mission Profile with movement of the mobile electric power system every third day (Chapter 4).

This study has explored current SOFC capabilities, described high-level considerations for a modularization plan, and identified potential benefits of adopting a simplified, modular approach to SOFC systems, which is anticipated to reduce training, streamline maintenance requirements, reduce logistics, and minimize procurement cost and simplify.

A future tasking, beyond the scope of this effort, could generate a matrix based the modularization approach described in Chapter 6, by obtaining priorities from all stakeholders, and performing a detailed analysis to develop a modularization plan that takes advantage of the solid oxide fuel cell technology and provides the most benefit to DOD.

References

Department of Defense (DOD), Military Standard 810E, *Environmental Test Methods and Engineering Guidelines* (DOD, released 14 July 1989).

DOD Program Manager, Mobile Electric Power, Proposed Department of Defense Handbook, MIL-HDBK-633F, *Standard Family of Mobile Electric Power Generating Sources, General Description Information and Characteristics Data Sheets*, prepared by Modern Technologies Corporation (MTC) (2004).

Directorate of Combat Developments for Ordnance, ATCL-O, U.S. Army Combined Arms Support Command, *Tactical Electric Power Operational Requirements Document (ORD) 0.5 kW to 200 kW Tactical Electric Power (TEP) ACAT LEVEL: 3*, prepared by Timothy Raney, MTC (7 July 2003).

Senate FY03 Defense Appropriations Bill (SRpt. 107-213), *Solid Oxide Fuel Cell Development*, line 52, "Military Engineering Advanced Technology."

Acronyms and Abbreviations

Term	Spellout
A2PT2O	Advanced Alternate Power Technologies Transformation Office
AFRL	Air Force Research Laboratory
AMMPS	Advanced Medium-Sized Mobile Power System
ANCOC	Advanced Noncommissioned Officer Course
AOR	Area of Operation
ASAT	Automatic System Approach to Training
BNCOC	Basic Noncommissioned Officer Course
CARC	Chemical Agent Resistant Coating
CERL	Construction Engineering Research Laboratory
CID	Commercial Item Description
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CRAF	Civil Reserve Air Fleet
CTC	Concurrent Technologies Corporation
DOD	Department of Defense
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse
USEPA	U.S. Environmental Protection Agency
ERDC	Engineer Research and Development Center
FCTec	Department of Defense Fuel Cell Test and Evaluation Center
FY	Fiscal Year
GAA	Grease Automotive and Artillery
GTI	Gas Technology Institute
HEMP	High Altitude Electromagnet Pulse
HMI	Human Machine Interface
kW	Kilowatt
LVAD	Low Velocity Air Drop
MEP	Mobile Electric Power
MEPGS	Mobile Electric Power Generating Sources
MIL-HDBK	Military Handbook
MIL-SPEC	Military Specification
MIL-STD	Military Standard
MOS	Military Occupational Specialty
MTBOMF	Mean Time Between Operational Mission Failures
MTG	Military Tactical Generator
MP	Mission Profile
MSDS	Material Safety Data Sheet
NATO	North Atlantic Treaty Organization
NBC	Nuclear, Biological, and Chemical
NET	New Equipment Training

Term	Spellout
NVIS	Night Vision Imaging System
PE	Program Element
OMMS	Ordnance Mechanical Maintenance School
ORD	Operational Requirements Document
PEM	Proton Exchange Membrane
PMCS	Preventive Maintenance Checks and Services
PM-MEP	Program Manager – Mobile Electric Power
PM-MEP2	Project Manager, Measurement, Electric Power and Protection
Q	Quarter
QSTAG	Quadripartite Standardization Agreements
RDTE	Research, Development, Test, and Evaluation
RF	Radio Frequency
ROI	Return on Investment
SBCT	Stryker Brigade Combat Team
SECA	Solid State Energy Conversion Alliance
SOFC	Solid Oxide Fuel Cell
TEP	Tactical Electrical Power
TMDE	Test, Measurement and Diagnostic Equipment
TQG	Tactical Quiet Generator
TSP	Training Support Package
WOAC	Warrant Officer Advance Course
WOBC	Warrant Officer Basic Course
WR-ALC	Warner Robins – Air Logistics Center

Appendix A: Federal and Military Specifications

1. Federal Specification A-A-52557 – *Fuel Oil, Diesel; for Posts, Camps, and Stations*
   This Commercial Item Description (CID) covers requirements for two grades of low-sulfur diesel fuel oils suitable for use in ground compression-ignition and gas turbine engines as well as other diesel fuel consuming equipment. This diesel fuel is identified as NATO Code Number F-54. This CID does not cover diesel fuels intended for use in areas where ambient temperatures lower than –32 °C generally occur.
2. Federal Specification A-A-52624 – *Antifreeze, Multi Engine Type*
   This CID covers the requirements for ethylene glycol-based and propylene glycol-based automotive engine antifreeze. The antifreeze is to be suitable for use in all administrative vehicles, construction, and material handling vehicles and equipment, and military ground combat and tactical vehicles and equipment.
3. Federal Specification A-A-55804 – *Rod, Ground* (with Attachments)
   This CID establishes the Government acquisition requirements for grounding electrodes with connecting cables and provisions for securing attachments to exposed noncurrent-carrying conductive materials of electrical equipment in mobile shops and temporary or permanent power stations, and to establish grounds in areas devoid of underground metallic water piping systems.
4. Federal Specification A-A-59616 – *Pipe Fittings: Bushings, Locknuts, and Plugs; Iron, Steel, and Aluminum; (Threaded)*; 125-150 lb
   This CID covers the general requirements for iron, steel, or aluminum bushings, locknuts, and plugs that are used with threaded piping at working pressures between 125 and 150 lb.
5. Military Specification MIL-PRF-2104 – *Lubricating Oil, Internal Combustion Engine, Combat/Tactical Service* (Not applicable to SOFC)
   This performance specification covers engine oils suitable for the lubrication of reciprocating internal combustion engines of both spark-ignition and compression-ignition types and for power transmission fluid applications in combat/tactical service equipment.
6. Military Specification MIL-PRF-2105 – *Lubricating Oil, Gear, Multipurpose (Metric)* (Not applicable to SOFC)
   This performance specification covers multi-purpose gear-lubricating oils.

7. Military Specification MIL-DTL-5624 – *Turbine Fuel, Aviation, Grades JP-4, JP-5, and JP-5/JP-8 ST*
8. Military Specification MIL-PRF-10924 – *Grease, Automotive, and Artillery*
   This specification covers one grade of a multi-purpose grease for the lubrication of ground vehicles, and equipment. It is identified by Military Symbol GAA and NATO Code Number G-403.
9. Military Specification MIL-PRF-21260 – *Lubricating Oil, Internal Combustion Engine, Preservative Break-In* (Not applicable to SOFC)
   This performance specification covers engine oils suitable for the preservation, break-in, and lubrication of reciprocating internal combustion engines of both spark-ignition and compression-ignition types. This Specification also covers power transmission fluid applications in equipment used in combat/tactical service.
10. Military Specification MIL-S-22473 – *Sealing, Locking, and Retaining Compounds: (Single Compound)*
    MIL-S-22473E, dated 12 April 1983, is hereby canceled. Future acquisitions for this item may refer to ASTM D5363, "Anaerobic Single-Component Adhesives."
11. Military Specification MIL-PRF-46167 – *Lubricating Oil, Internal Combustion Engine, Arctic (Not applicable to SOFC*
    This performance specification covers one grade of internal combustion engine lubricating oil with military symbol OEA-30 and NATO Code O-184, suitable for arctic use.
12. Military Specification MIL-A-53009 – *Additive, Antifreeze Extender, Liquid Cooling Systems*
    This specification covers one type and one grade of additive intended for inhibiting water or reinhibiting used MIL-A-46153 antifreeze.
13. Military Specification MIL-C-53072 – *Chemical Agent Resistant Coating (CARC) System Application Procedures and Quality Control Inspection*
    This document covers the general requirements for application and inspection of the chemical agent resistant coating (CARC) system used on tactical military equipment. It is intended for use as a guide in selection of the appropriate materials and procedures.
14. Military Specification MIL-DTL-64159 – *Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant*
    This specification covers water-dispersible, chemical agent resistant, aliphatic polyurethane coatings for use as a finish coat on all military tactical equipment including ground, aviation, and related support assets.
15. Military Specification MIL-DTL-83133 – *Turbine Fuels, Aviation, Kerosene Types, NATO F-34 (JP-8), NATO F-35, and JP-8 + 100*
    This specification covers three grades of kerosene type aviation turbine fuel, NATO F-34 (JP-8), NATO F-35, and JP-8+100. This specification was thoroughly reviewed as a part of acquisition reform. While most of the requirements were

converted to performance terms, due to the military-unique nature of the product and the need for compatibility with deployed systems, it was determined that not all requirements could be converted. The issuance of this specification as "detail" is not intended to constrain technology advances in future systems.

16. Military Specification MIL-L-85762 – *Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible*
    This specification covers two grades of aviation turbine fuel NATO F-40 (JP-4) and NATO F-44 (JP-5). This specification establishes performance, general configuration, and test and acceptance requirements for NVIS compatible aircraft interior lighting. It is applicable to all systems, subsystems, component equipment, and hardware providing the lighting environment in aircraft crew stations and compartments where NVIS are employed.

Appendix B: Federal and Military Standards

1. Federal Standard FED-STD-595 – *Colors Used in Government Procurement*
   This standard presents the colors used by Government activities in a format suitable for color selection, color matching and for quality control inspection. This document describes the designation and use of the color chips of this standard.
2. Military Standard MIL-STD-130 – *Identification Marking of U.S. Military Property*
   This standard provides the item marking criteria for development of specific marking requirements and methods for identification of items of military property produced, stocked, stored, and issued by or for the Department of Defense. This standard addresses criteria and data content for both human-readable information and machine-readable information applications of item identification marking.
3. Military Standard MIL-STD-209 – *Lifting and Tie Down Provisions*
   This standard covers the design and testing of slinging, tie-down, and cargo tie-down provisions. The requirements in this standard are military-unique interface requirements developed specifically for ensuring that the lifting and tie-down provisions on military equipment meet the physical, functional and operational environment attributes for transportation assets of the Defense Transportation System.
4. Military Standard MIL-STD-461 – *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*
   This standard establishes interface and associated verification requirements for the control of the electromagnetic interference (emission and susceptibility) characteristics of electronic, electrical, and electromechanical equipment and subsystems designed or procured for use by activities and agencies of the Department of Defense. Such equipment and subsystems may be used independently or as an integral part of other subsystems or systems. This standard is best suited for items that have the following features: electronic enclosures that are no larger than an equipment rack, electrical interconnections that are discrete wiring harnesses between enclosures, and electrical power input derived from prime power sources. This standard should not be directly applied to items such as modules located inside electronic enclosures or entire platforms. The principles in this

standard may be useful as a basis for developing suitable requirements for those applications.

5. Military Standard MIL-STD-705 – *Generator Sets, Engine Driven, Methods of Tests and Instructions*
   This standard covers five series of specific test methods for testing and determining the characteristics of electric generators, generator sets, and associated equipment. This standard establishes methods of testing for determining characteristics desired by the military departments to ensure that electrical generators and generator sets comply with military requirements. Except as indicated in the applicable procurement documents, the test methods now appearing in the various joint-service specifications for testing electric generators and electric generator sets will be superseded by this standard. This standard establishes uniform test methods for the military services, uniform test equipment and facilities, and uniform procedures for setting up and conducting the various tests. These methods provide for conservation of manpower, materials, equipment, and facilities. This standard does not establish limiting values for the results of the tests nor does it specify the tests required for any specific electric generator or generator set.
6. Military Standard MIL-STD-810 – *Environmental Engineering Considerations and Laboratory Tests*
   This standard provides guidelines for conducting environmental engineering tasks to tailor environmental tests to end-item equipment applications and test methods for determining the effects of natural and induced environments on equipment used in military applications.
7. Military Standard MIL-STD-814 – *Requirements for Tie Down, Suspension, and Extraction Provisions on Military Materiel for Airdrop*
   This standard establishes the design, number, and location requirements of airdrop tie down, suspension, and extraction provisions on airdrop items delivered by Low Velocity Airdrop (LVAD).
8. Military Standard MIL-STD-882 – *System Safety*
   This document outlines a standard practice for conducting system safety. The system safety practice as defined herein conforms to the acquisition procedures in DOD Regulation 5000.2-R and provides a consistent means of evaluating identified risks. Mishap risk must be identified, evaluated, and mitigated to a level acceptable (as defined by the system user or customer) to the appropriate authority and compliant with Federal (and State where applicable) laws and regulations, Executive Orders, treaties, and agreements. Program trade studies associated with mitigating mishap risk must consider total life-cycle cost in any decision. When requiring MIL-STD-882 in a solicitation or contract and no specific paragraphs of this standard are identified, then apply only those requirements presented in Section 5.

9. Military Standard MIL-STD-889 – *Dissimilar Metals*
   This standard defines and classifies dissimilar metals and establishes requirements for protecting couple dissimilar metals, with attention directed to the anodic member of the couple, against corrosion.
10. Military Standard MIL-STD-913 – *Requirements for the Certification of Sling Loaded Military Equipment for External Transportation by Department of Defense Helicopters*
    This military standard delineates the requirements and procedures for the certification of sling loaded military equipment for external transportation by DOD helicopters.
11. Military Standard MIL-STD-1472 – *Human Engineering*
    Military Standard MIL-STD-1553 – *Digital Time Division Command/Response Multiplex Data Bus*
    This standard contains requirements for a digital time division command/response multiplex data bus for use in systems integration.
    Military Standard MIL-STD-2169 – *High Altitude Electro-Magnetic Pulse Environment (SECRET)*
    This standard establishes general human engineering design criteria for military systems, subsystems, equipment, and facilities. Cannot be discussed in this forum; however, CTC can obtain with the proper approvals.
    USCENTCOM 415-1, *Contingency and Long Term Base Camp Facilities Standards*, "The Sand Book"
    This publication provides guidance for the planning and development of contingency base camps, long-term base camps, and aerial ports of embarkation/debarkation (APOE/APOD) that support associated missions IAW with Joint Publication 4-04 (Joint Doctrine for Civil Engineer Support). In addition, it provides consistent standards and expectations across the service components for infrastructure development, security, sustainment, survivability (essential for the quality of life), safety, and affordable working and living environments for personnel in the U.S. Central Command (USCENTCOM) Area of Operation Responsibility (AOR).

Appendix C: Military Handbooks and Field Manuals

1. Military Handbook MIL-HDBK-705 – *Generator Sets, Electrical, Measurement, and Instrumentation Methods*
   This handbook covers two series of methods for measuring and determining characteristics of all electric generators and generator sets as classified by MIL-STD-1332, and associated equipment. The illustration and description of the test instruments together with instructions for their use are included as applicable under each method.
2. Military Handbook MIL-HDBK-784 – *Guidelines-Design to Minimize Contamination and to Facilitate Decontamination of Military Vehicles and Other Equipment: Interiors and Exteriors*
   This handbook provides guidelines for designing military equipment that minimizes contamination by nuclear, biological, and chemical (NBC) agents and increases the effectiveness of decontamination processes. In no way do these guidelines presume to dictate requirements for the layout, configuration, construction of military hardware, or for the selection of materials to be used therein; nor do they prescribe presently used design techniques. Rather, they are intended to bring the problems of contamination and decontamination to the attention of designers and to suggest approaches that can eliminate these problems and can make decontamination easier.
3. Military Handbook MIL-HDBK-810 – *Environmental Engineering Considerations and Laboratory Tests*
   This standard provides guidelines for conducting environmental engineering tasks to tailor environmental tests to end-item equipment applications and test methods for determining the effects of natural and induced environments on equipment used in military applications.
4. Military Handbook MIL-HDBK-831 – *Preparation of Test Reports*
   This handbook delineates the format and content criteria to be used in the preparation of test reports covering tests on systems, subsystems, equipment, components, and parts. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.
5. Military Handbook MIL-HDBK-1791 – *Designing for Internal Aerial Delivery in Fixed Wing Aircraft*
   This standard covers general design and performance requirements of military equipment for internal air transport in military prime mission cargo aircraft and

the long-range international segment of the Civil Reserve Air Fleet (CRAF). This standard also contains general design and performance requirements for military equipment to be airdropped from Air Force cargo aircraft. The complete air transportability and airdrop requirements for an item of equipment not specified herein shall be specified in the individual equipment specification.

6. Field Manual FM 5-422 –E*ngineer Prime Power Operations*
   This Field Manual (FM) provides a doctrinal basis for planning and employing engineer prime power assets in the theater of operations (TO). It describes the responsibilities, relationships, capabilities, constraints, planning considerations, and logistics requirements associated with engineer prime power operations. The fundamental purpose of this manual is to integrate prime power operations into the overall sustainment engineering structure. The doctrine presented is applicable to operations across the entire continuum of military operations. The manual was designed for all commanders and planning staffs who require engineer prime power support or those who must provide engineer prime power support.

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14. ABSTRACT

This work represents an early step in the Military Solid Oxide Fuel Cell (SOFC) development process. This study identifies: (1) the military's current and future electric power needs and capabilities, (2) the requirements for building a military SOFC power system with design recommendations, and (3) an initial approach to a Modularization Plan for developing military SOFC technology. The goals of this Modularization Plan will be to minimize procurement, training, and maintenance costs. Existing generators will be replaced with future electric power systems requiring reduced weight and footprint. Fuel efficiency goals will reduce fuel tanker fleet size and further decrease the logistical footprint. Military Standards, Specifications, and Handbooks pertaining specifically to SOFCs are not available, nor planned. This report identifies documents pertinent to the development of solid oxide fuel cell systems (<60 kW) based on information gathered through assessments of current applications and procurement requirements for military electric power. The report offers design recommendations to minimize the procurement cost of the SOFC system. The report discusses current capabilities, provides high-level considerations for a modularization plan, and identifies potential benefits of adopting a modular approach to SOFC systems, which is anticipated to reduce training, streamline the maintenance requirements, and reduce logistics.

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